

(12) **United States Patent**
Yoneda et al.

(10) **Patent No.:** **US 9,362,042 B2**
(45) **Date of Patent:** **Jun. 7, 2016**

(54) **ELECTRONIC COMPONENT**

(56) **References Cited**

(71) Applicant: **MURATA MANUFACTURING CO., LTD.**, Kyoto (JP)

(72) Inventors: **Masayuki Yoneda**, Nagaokakyo (JP);
Kenji Yoshida, Nagaokakyo (JP);
Yasunari Nakashima, Nagaokakyo (JP)

(73) Assignee: **Murata Manufacturing Co., Ltd.**,
Kyoto-fu (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/203,497**

(22) Filed: **Mar. 10, 2014**

(65) **Prior Publication Data**
US 2014/0306792 A1 Oct. 16, 2014

(30) **Foreign Application Priority Data**
Apr. 11, 2013 (JP) 2013-083048

(51) **Int. Cl.**
H01F 5/00 (2006.01)
H01F 27/26 (2006.01)
H01F 27/28 (2006.01)
H01F 17/00 (2006.01)

(52) **U.S. Cl.**
CPC **H01F 27/2804** (2013.01); **H01F 17/0013** (2013.01); **H01F 2017/002** (2013.01)

(58) **Field of Classification Search**
CPC H01F 5/00; H01F 27/28
USPC 336/200, 232
See application file for complete search history.

U.S. PATENT DOCUMENTS

5,515,022 A *	5/1996	Tashiro	.....	H01F 17/0013	174/262
6,580,350 B1	6/2003	Kobayashi			
7,135,951 B1	11/2006	Sidhu et al.			
2008/0048813 A1 *	2/2008	Mosley et al.	.....	336/65	
2008/0246579 A1 *	10/2008	Mizuno et al.	.....	336/205	
2009/0115563 A1 *	5/2009	Arata	.....	H01F 17/0013	336/200
2010/0194513 A1	8/2010	Ozawa et al.			
2010/0328009 A1 *	12/2010	Tawa	.....	336/200	
2013/0176096 A1 *	7/2013	Takahashi	.....	336/200	

FOREIGN PATENT DOCUMENTS

JP	2000-286125 A	10/2000
JP	2008-004605 A	1/2008
JP	2009-117664 A	5/2009
JP	2010-192889 A	9/2010
WO	WO 2007072612 A1 *	6/2007

OTHER PUBLICATIONS

An Office Action; "Notification of Reasons for Rejection," issued by the Japanese Patent Office on Feb. 24, 2015, which corresponds to Japanese Patent Application No. 2013-083048 and is related to U.S. Appl. No. 14/203,497; with English language translation.

* cited by examiner

Primary Examiner — Tsz Chan
(74) *Attorney, Agent, or Firm* — Studebaker & Brackett PC

(57) **ABSTRACT**

An electronic component having: a laminate formed by laminating a plurality of insulator layers; and a coil consisting of linear coil conductor layers that are laminated along with the insulator layers, the coil having a spiral form or a helical form that windingly extends in a direction of lamination. In a cross section perpendicular to a direction in which the coil conductor layers extend, the coil conductor layers have recesses provided in their surfaces directed toward an inner circumference side of the coil, the recesses being set back toward an outer circumference side of the coil.

9 Claims, 15 Drawing Sheets

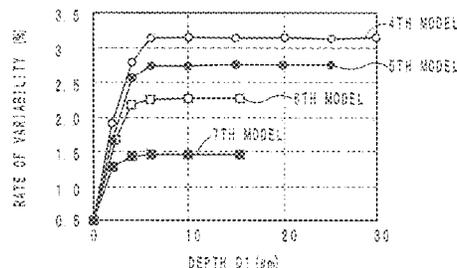
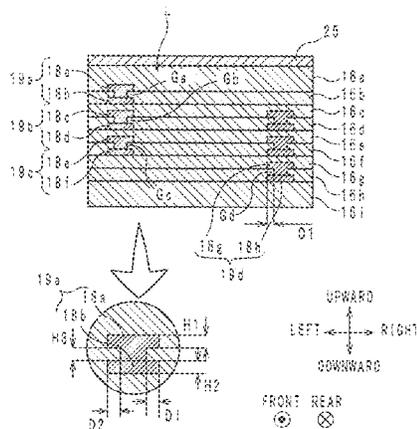


FIG. 1

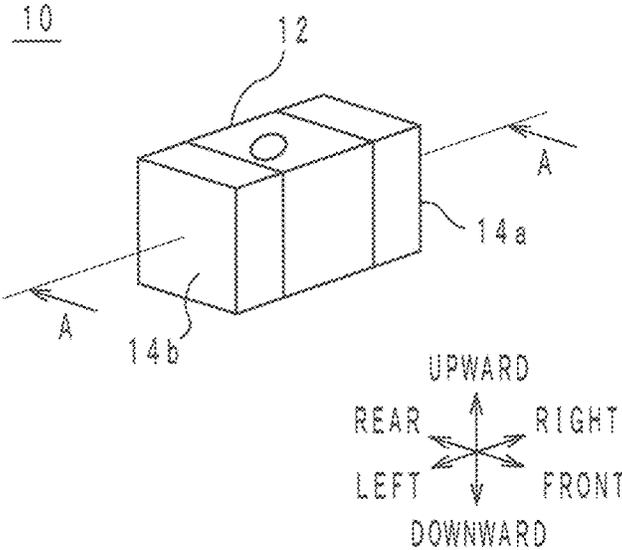


FIG. 2

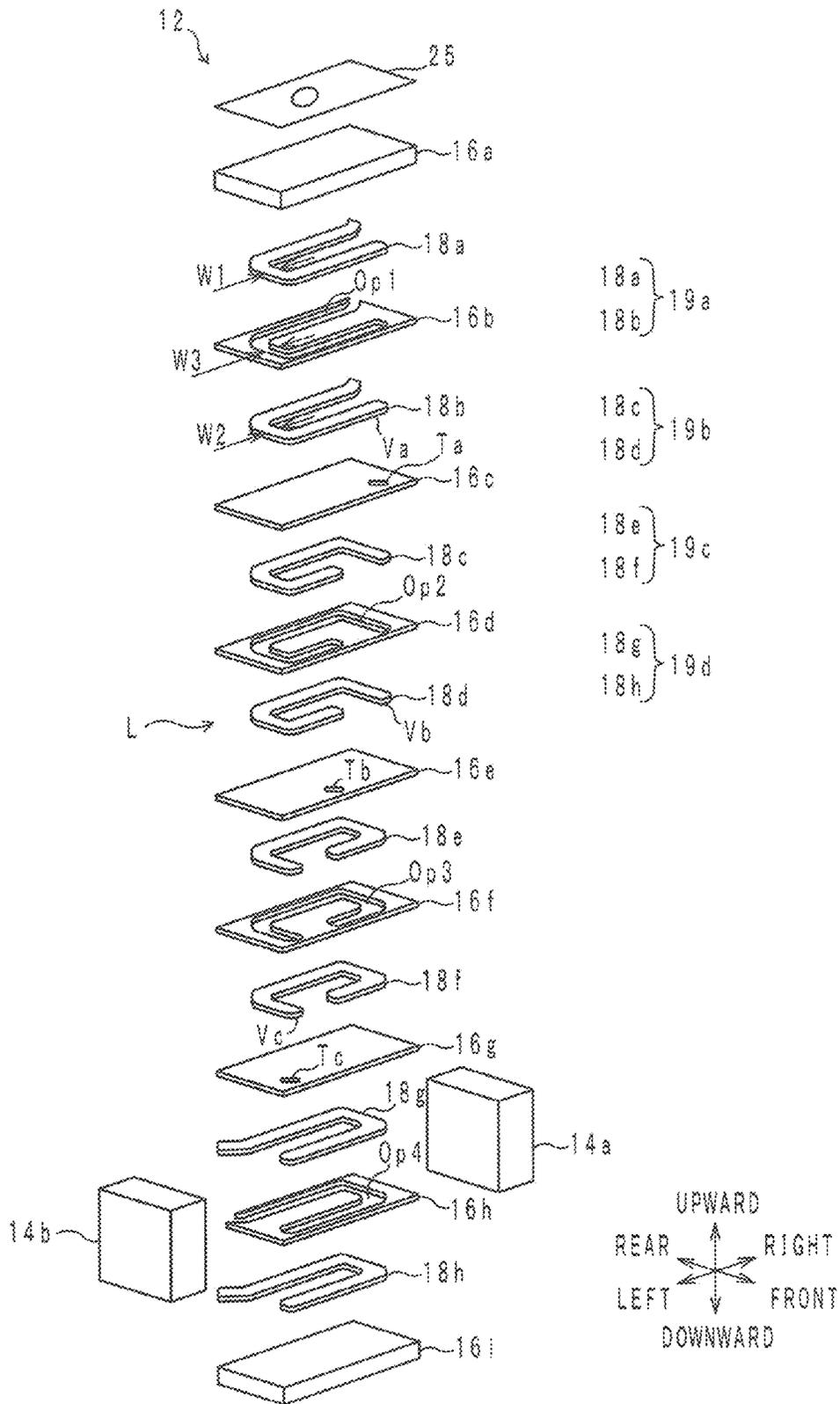


FIG. 3

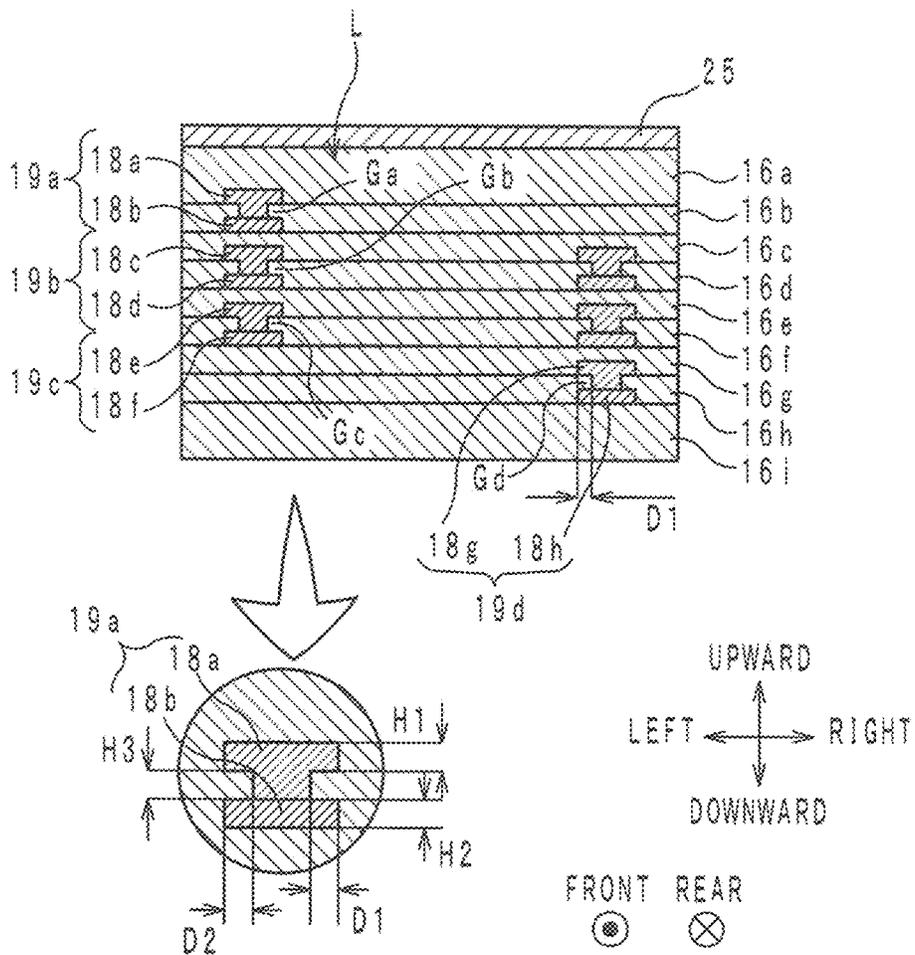


FIG. 4

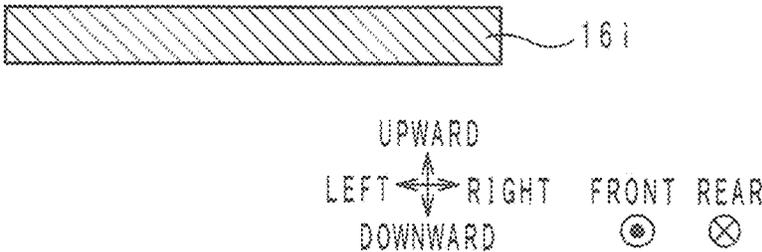


FIG. 5

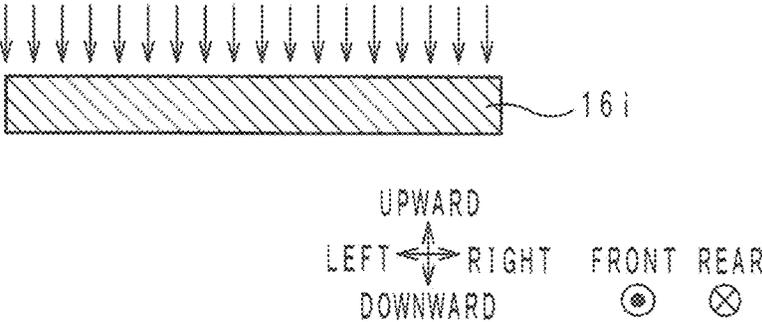


FIG. 6

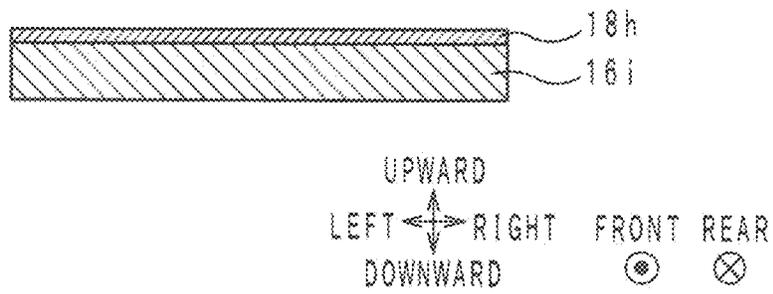


FIG. 7

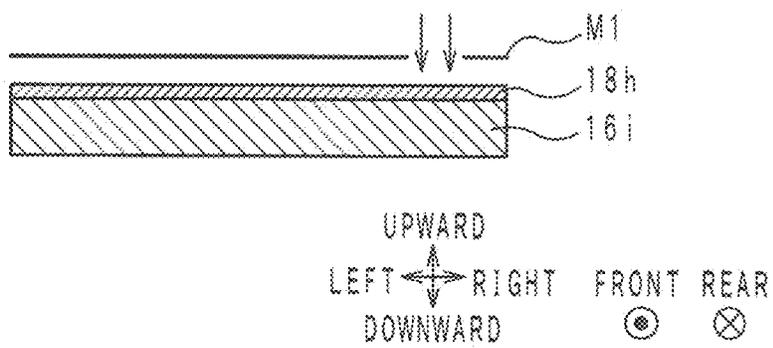


FIG. 8

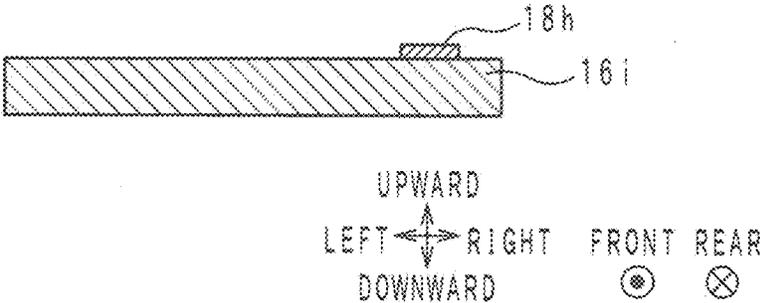


FIG. 9

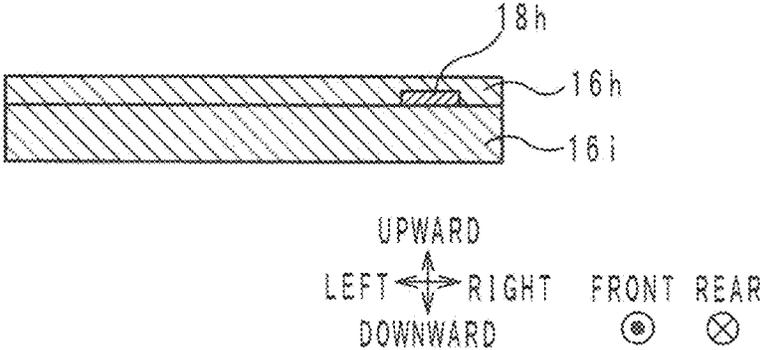


FIG. 10

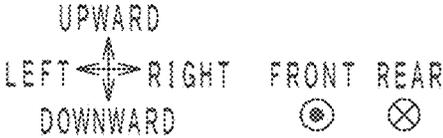
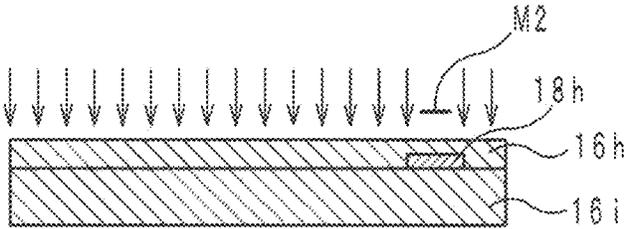


FIG. 11

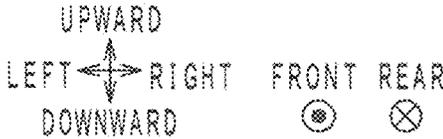
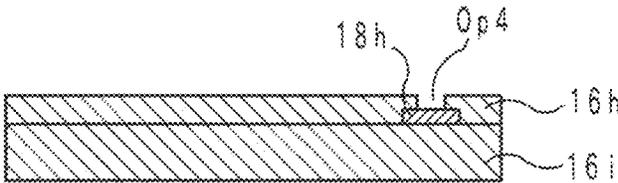


FIG. 12

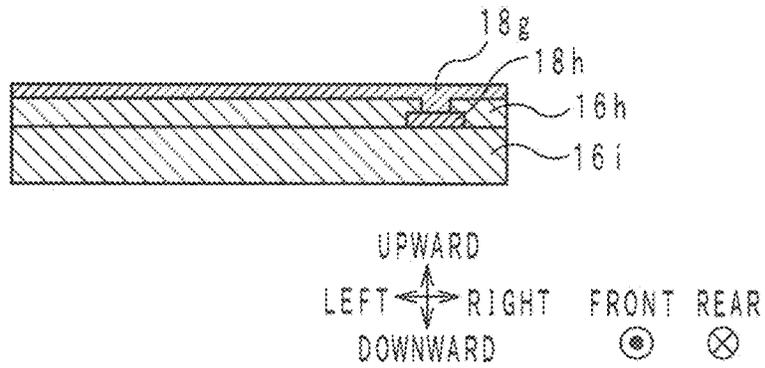


FIG. 13

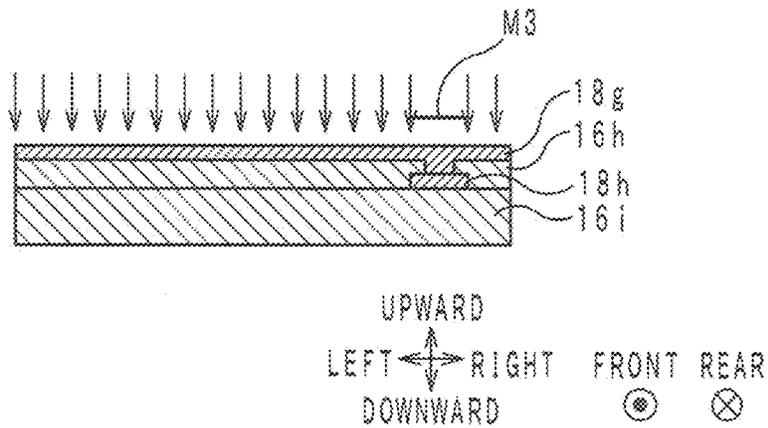


FIG. 14

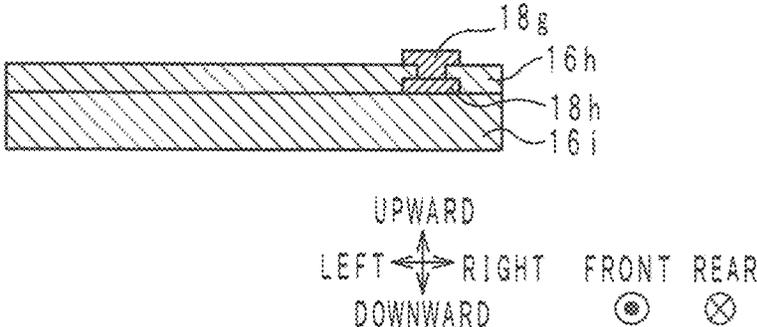


FIG. 15

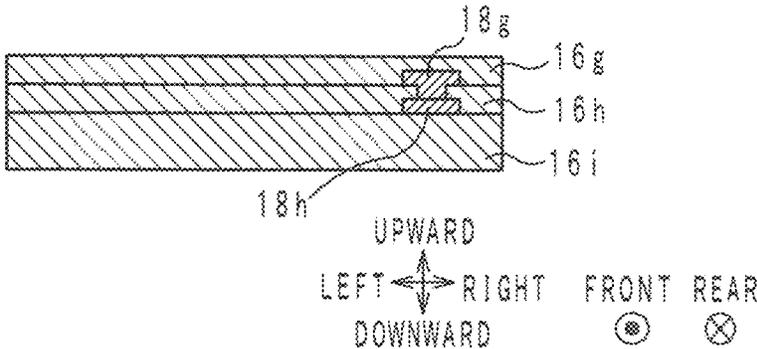


FIG. 16

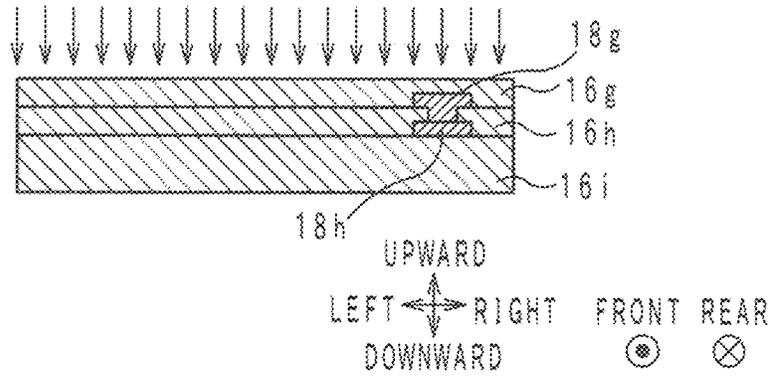


FIG. 17

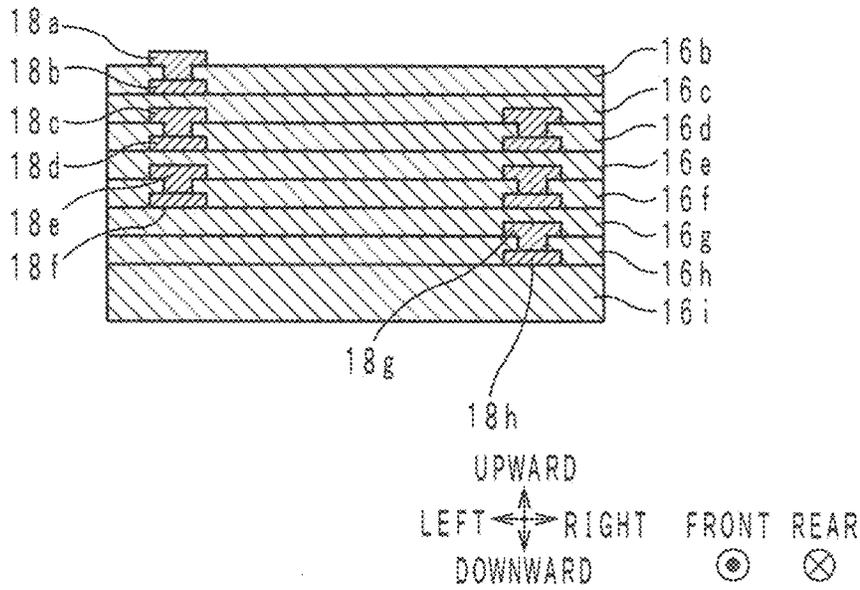


FIG. 18

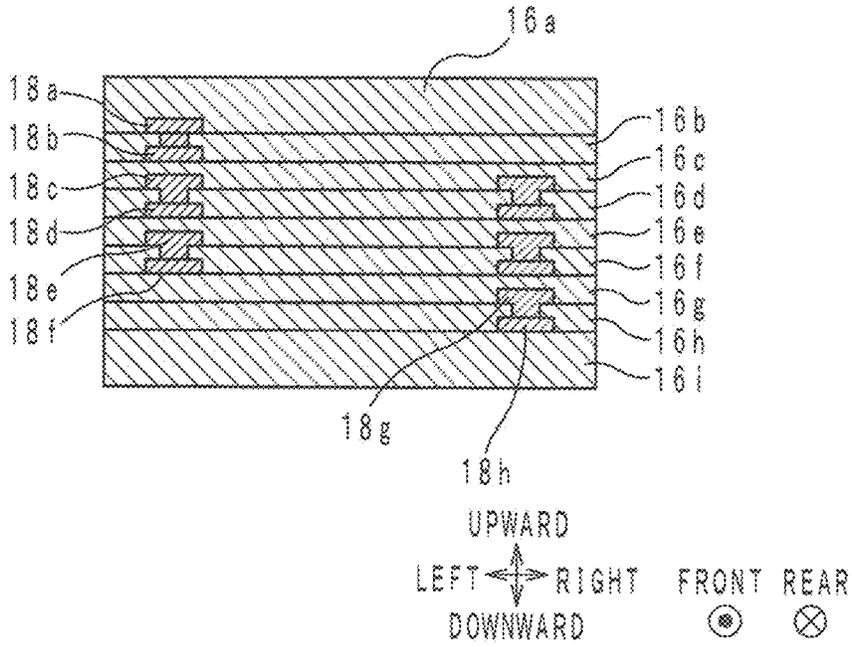


FIG. 19

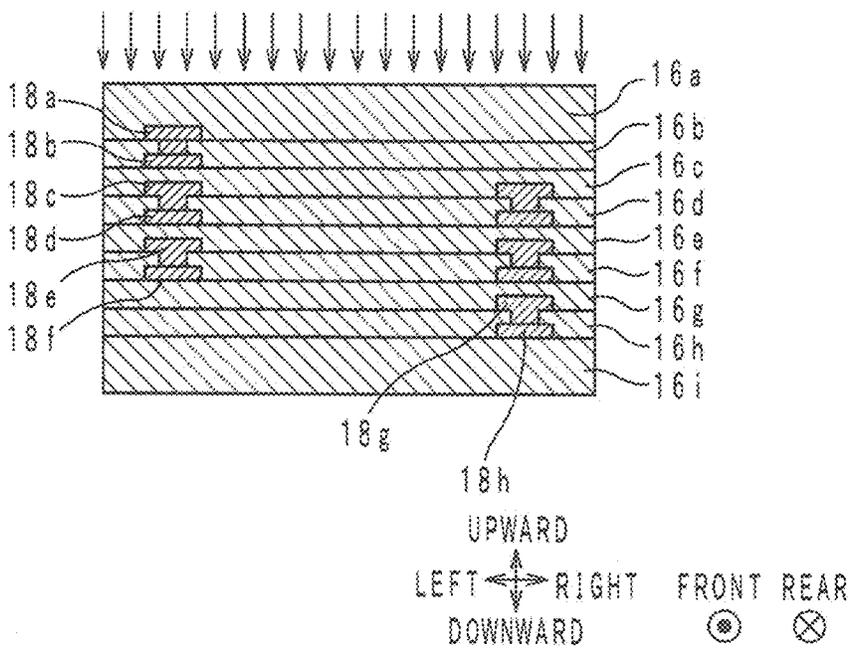


FIG. 20

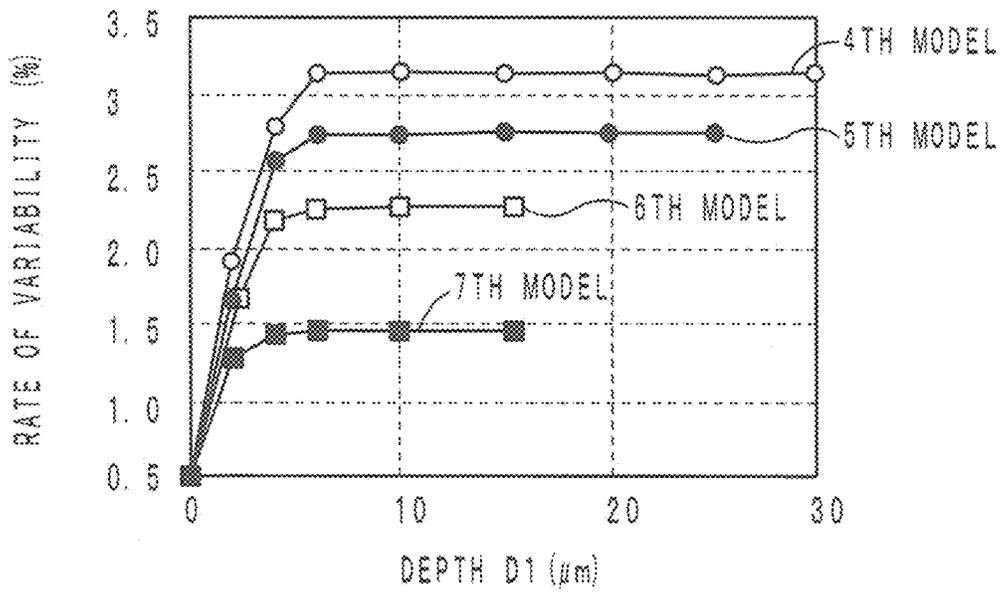


FIG. 21

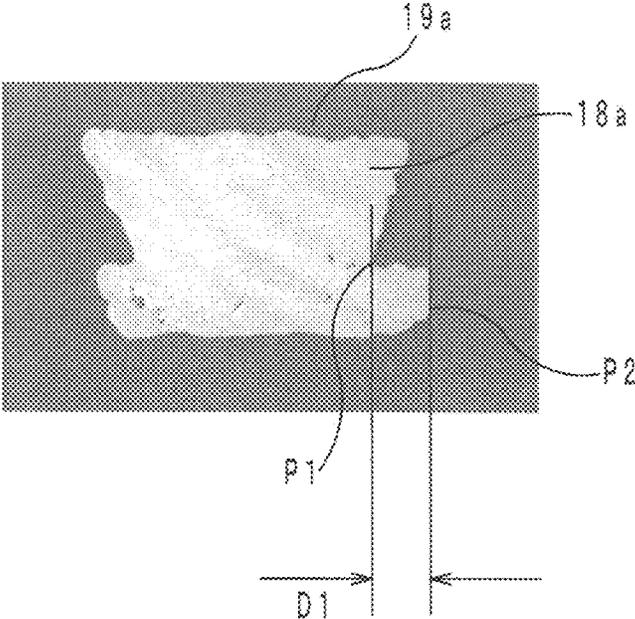


FIG. 22

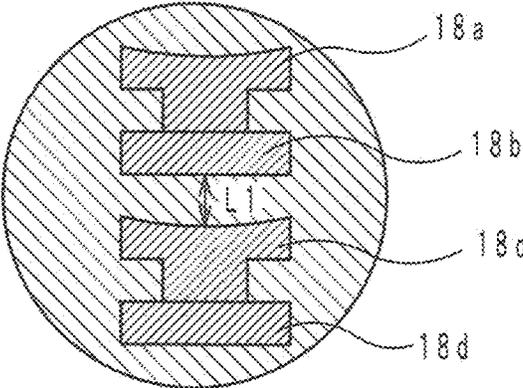
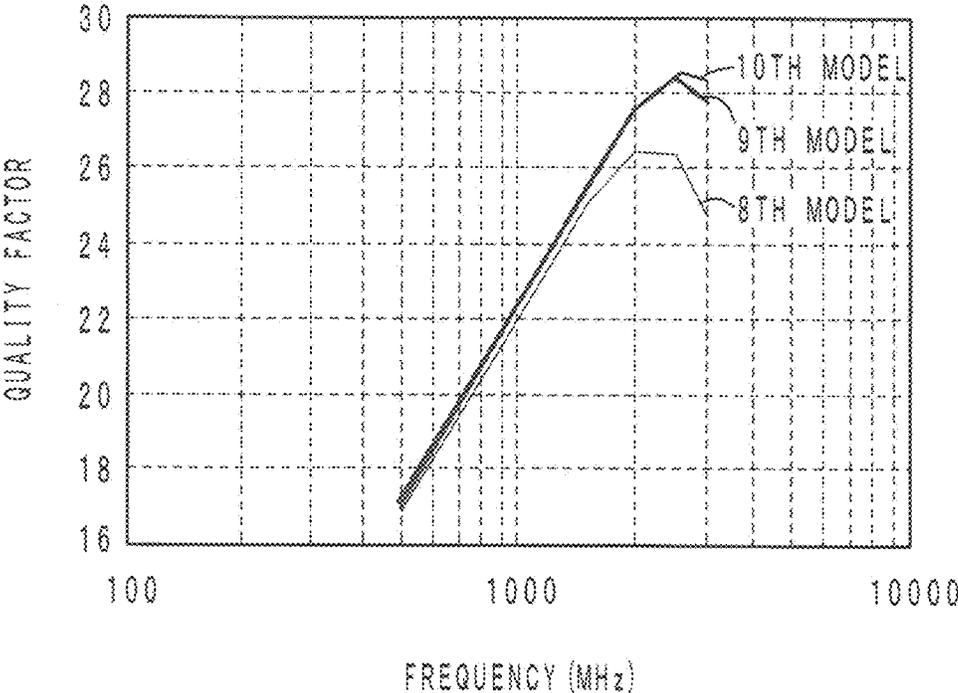


FIG. 23



1

ELECTRONIC COMPONENT

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims benefit of priority to Japanese Patent Application No. 2013-083048 filed on Apr. 11, 2013, the entire content of which is incorporated herein by reference.

TECHNICAL FIELD

The technical field relates to electronic components, more particularly to an electronic component with an internal coil.

BACKGROUND

As an disclosure relevant to a conventional electronic component, a multilayer electronic component disclosed in, for example, Japanese Patent Laid-Open Publication No. 2000-286125, is known. This multilayer electronic component includes a laminate and a coil. The laminate is formed by laminating a plurality of ferrite sheets. The coil includes a plurality of coil conductor patterns that are connected via through-holes so as to wind helically in the direction of lamination.

Incidentally, to achieve, for example, a low direct-current resistance in the coil, the multilayer electronic component disclosed in Japanese Patent Laid-Open Publication No. 2000-286125 is required to have wider or thicker coil conductor patterns, but in such a case, it is difficult to achieve a large inductance value. More specifically, in the case of a helical coil, the density of magnetic flux in the coil is high. In this case, magnetic flux that does not flow through the coil passes through the surfaces of the coil conductor patterns. Because a high-frequency signal flows through the coil, the direction of magnetic flux generated by the coil varies cyclically. In the case where the direction of magnetic flux that passes through the coil conductor patterns varies cyclically, eddy currents are generated in the coil conductor patterns, so that Joule's heat is produced. As a result, an eddy-current loss occurs, leading to a reduced inductance value of the coil.

SUMMARY

An electronic component according to an embodiment of the present disclosure includes a laminate formed by laminating a plurality of insulator layers, and a coil including linear coil conductor layers laminated along with the insulator layers, the coil having a helical form, which windingly extends in a direction of lamination, or a spiral form. In a cross section perpendicular to a direction in which the coil conductor layers extend, the coil conductor layers have recesses provided in their surfaces directed toward an inner circumference side of the coil, the recesses being set back toward an outer circumference side of the coil.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an external oblique view of an electronic component according to an embodiment.

FIG. 2 is an exploded oblique view of the electronic component in FIG. 1.

FIG. 3 is a cross-sectional structure view of a laminate of the electronic component taken along line A-A of FIG. 1 and an enlarged area of the laminate.

2

FIG. 4 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 5 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 6 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 7 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 8 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 9 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 10 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 11 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 12 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 13 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 14 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 15 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 16 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 17 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 18 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 19 is a cross-sectional view corresponding to a step in the production of the electronic component.

FIG. 20 is a graph showing simulation results.

FIG. 21 is a photograph showing a cross-sectional structure of a coil conductor layer.

FIG. 22 is a cross-sectional structure view of a coil conductor layer.

FIG. 23 is a graph showing simulation results.

DETAILED DESCRIPTION

Hereinafter, an electronic component according to an embodiment of the present disclosure will be described.

Structure of Electronic Component

The structure of the electronic component according to the embodiment will be described below with reference to the drawings. FIG. 1 is an external oblique view of the electronic component 10 according to the embodiment. FIG. 2 is an exploded oblique view of the electronic component 10 in FIG. 1. FIG. 3 is a cross-sectional structural view of a laminate 12 of the electronic component 10 taken along line A-A of FIG. 1. In FIG. 3, external electrodes 14a and 14b are not shown. In the following, the direction of lamination of the laminate 12 will be defined as a top-bottom direction. In addition, when the laminate 12 is viewed in a top view, the direction in which the short side of the laminate 12 extends will be defined as a front-back direction, and the direction in which the long side of the laminate 12 extends will be defined as a right-left direction.

As shown in FIGS. 1 through 3, the electronic component 10 includes the laminate 12, the external electrodes 14a and 14b, and a coil L. The laminate 12 is in the form of a rectangular solid formed by laminating insulator layers 25 and 16a to 16i. The insulator layers 25 and 16a to 16i are laminated in this order, from top to bottom, and have rectangular edges.

The insulator layer **25** has a blank circle marked thereon. The blank circle is used as a direction marker. Moreover, the insulator layers **16b**, **16d**, **16f**, and **16h** have respective openings Op1 to Op4 provided therein. In addition, the insulator layers **16c**, **16e**, and **16g** have respective through-holes Ta to Tc provided therein. In this manner, the insulator layers **16b**, **16d**, **16f**, and **16h** with the openings Op1 to Op4 and the insulator layers **16c**, **16e**, and **16g** without openings are laminated so as to alternate with each other. The openings Op1 to Op4 and the through-holes Ta to Tc will be described later. The insulator layers **16a** to **16i** are made from glass containing a magnetic material. Upper and lower surfaces of the insulator layers **16a** to **16i** will be referred to below as top and bottom surfaces, respectively.

The coil L spirals clockwise when viewed in a top view, so as to take a helical form continuing from bottom to top. The coil L includes coil conductor layers **19a** to **19d** and via-hole conductors Va to Vc. The coil conductor layers **19a** to **19d** are linear conductors laminated along with the insulator layers **16a** to **16i**, and when viewed in a top view, they wind clockwise around the center of the laminate **12** (the intersection of diagonals). The coil conductor layers **19a** to **19d** are made of, for example, a conductive material mainly composed of Ag. In the following, the ends of the coil conductor layers **19a** to **19d** that are located upstream in the clockwise direction will be simply referred to as the upstream ends, and the ends of the coil conductor layers **19a** to **19d** that are located downstream in the clockwise direction will be simply referred to as the downstream ends.

Furthermore, the coil conductor layer **19a** includes coil conductor layers **18a** and **18b**, as shown in FIG. 2. The coil conductor layers **18a** and **18b** have approximately the same shape when viewed in a top view, and are stacked vertically. More specifically, the coil conductor layer **18b** is positioned on the top surface of the insulator layer **16c**. The opening Op1 is provided in the insulator layer **16b**, as mentioned earlier. The opening Op1 has a linear shape which, when viewed in a top view, overlaps with the coil conductor layer **18b** and is approximately the same as the shape of the coil conductor layer **18b**. However, the width W3 of the opening Op1 is less than both the width W1 of the coil conductor layer **18a** and the W2 of the coil conductor layer **18b**.

The coil conductor layer **18a** is provided on the top surface of the insulator layer **16b** so as to be partially positioned in the opening Op1, as shown in FIGS. 2 and 3. Note that the coil conductor layer **18a**, when viewed in a top view, reaches beyond the edge of the opening Op1 on the top surface of the insulator layer **16b**. Accordingly, in a cross section perpendicular to the direction in which the coil conductor layer **18a** extends, the coil conductor layer **18a** is in the shape of a T. Moreover, the lower surface of the coil conductor layer **18a** contacts the upper surface of the coil conductor layer **18b**. Accordingly, in a cross section perpendicular to the direction in which the coil conductor layer **19a** extends, the coil conductor layer **19a** is in the shape of an H rotated 90 degrees. Therefore, in the cross section perpendicular to the direction in which the coil conductor layer **19a** extends, the surface of the coil conductor layer **19a** that is directed toward the inner circumference side of the coil L has a recess Ga set back toward the outer circumference side of the coil L. The depth D1 of the recess Ga (see FIG. 3) is preferably 6 μm or more, which is 40% or less of the width W1 or W2 of the coil conductor layers **18a** to **18h**.

The coil conductor layer **19b** includes the coil conductor layers **18c** and **18d**, as shown in FIG. 2. The coil conductor layer **19c** includes the coil conductor layers **18e** and **18f**, as shown in FIG. 2. The coil conductor layer **19d** includes the

coil conductor layers **18g** and **18h**, as shown in FIG. 2. The configurations of the coil conductor layers **19b** to **19d** are similar to that of the coil conductor layer **19a**, and therefore, any descriptions thereof will be omitted. Moreover, the configurations of the openings Op2 to Op4 are similar to that of the opening Op1, and therefore, any descriptions thereof will be omitted.

The through-holes Ta to Tc are holes that vertically pierce through the insulator layers **16c**, **16e**, and **16g**, respectively. The through-hole Ta, when viewed in a top view, overlaps with both the upstream end of the coil conductor layer **18b** and the downstream end of the coil conductor layer **18c**. The through-hole Tb, when viewed in a top view, overlaps with both the upstream end of the coil conductor layer **18d** and the downstream end of the coil conductor layer **18e**. The through-hole Tc, when viewed in a top view, overlaps with both the upstream end of the coil conductor layer **18f** and the downstream end of the coil conductor layer **18g**.

The via-hole conductor Va projects downward from the upstream end of the coil conductor layer **18b** so as to be positioned in the through-hole Ta. Accordingly, the via-hole conductor Va connects the upstream end of the coil conductor layer **18b** to the downstream end of the coil conductor layer **18c**. The via-hole conductor Vb projects downward from the upstream end of the coil conductor layer **18d** so as to be positioned in the through-hole Tb. Accordingly, the via-hole conductor Vb connects the upstream end of the coil conductor layer **18d** to the downstream end of the coil conductor layer **18e**. The via-hole conductor Vc projects downward from the upstream end of the coil conductor layer **18f** so as to be positioned in the through-hole Tc. Accordingly, the via-hole conductor Vc connects the upstream end of the coil conductor layer **18f** to the downstream end of the coil conductor layer **18g**. Thus, the coil conductor layers **19a** to **19d** are connected by the via-hole conductors Va to Vc, thereby forming the helical coil L.

The external electrode **14a** covers the right end surface of the laminate **12**, and is bent toward the top, bottom, front, and back surfaces of the laminate **12**. The downstream end of the coil conductor layer **19a** is led out to the right end surface of the laminate **12**. Accordingly, the downstream end of the coil conductor layer **19a** is connected to the external electrode **14a**.

The external electrode **14b** covers the left end surface of the laminate **12**, and is bent toward the top, bottom, front, and back surfaces of the laminate **12**. The upstream end of the coil conductor layer **19d** is led out to the left end surface of the laminate **12**. Accordingly, the upstream end of the coil conductor layer **19d** is connected to the external electrode **14b**.

Method for Producing Electronic Component

Next, the method for producing the electronic component **10** will be described with reference to the drawings. FIGS. 4 through 19 are cross-sectional views corresponding to the steps in the production of the electronic component **10**. While the following description focuses on the process of producing one electronic component **10**, in actuality, a mother laminate is produced and cut, thereby obtaining a plurality of electronic components **10** simultaneously.

Initially, a photosensitive insulator paste is applied by printing, as shown in FIG. 4. Thereafter, the entire surface of the photosensitive insulator paste is exposed to light, as shown in FIG. 5. As a result, the photosensitive insulator paste is cured, so that an insulator layer **16i** is formed.

Next, a photosensitive conductor paste is applied by printing onto the insulator layer **16i**, as shown in FIG. 6. Thereaf-

5

ter, the photosensitive conductor paste is exposed to light through a mask M1, as shown in FIG. 7. The mask M1 has an opening having the same shape as a coil conductor layer 18h. As a result, a portion of the photosensitive conductor paste that is to become a coil conductor layer 18h is cured. Moreover, the remaining uncured paste is removed by a developer, as shown in FIG. 8. As a result, a coil conductor layer 18h is formed.

Next, a photosensitive insulator paste is applied by printing onto the insulator layer 16i and the coil conductor layer 18h, as shown in FIG. 9. Thereafter, the photosensitive conductor paste is exposed to light through a mask M2, as shown in FIG. 10. The mask M2 covers a portion of the photosensitive insulator paste where an opening Op4 is to be provided. As a result, the photosensitive conductor paste, other than the portion where an opening Op4 is to be provided, is cured. Moreover, the remaining uncured paste is removed by a developer, as shown in FIG. 11. As a result, an insulator layer 16h is formed.

Next, a photosensitive insulator paste is applied by printing onto the insulator layer 16h and also into the opening Op4, as shown in FIG. 12. Thereafter, the photosensitive conductor paste is exposed to light through a mask M3, as shown in FIG. 13. The mask M3 has an opening having the same shape as a coil conductor layer 18g. As a result, a portion of the photosensitive conductor paste that is to become a coil conductor layer 18g is cured. Moreover, the remaining uncured paste is removed by a developer, as shown in FIG. 14. As a result, a coil conductor layer 18g is formed.

Next, a photosensitive insulator paste is applied by printing onto the insulator layer 16h and the coil conductor layer 18g, as shown in FIG. 15. Thereafter, the photosensitive conductor paste is exposed to light through an unillustrated mask, as shown in FIG. 16. The unillustrated mask covers a portion of the photosensitive insulator paste where a through-hole Tc is to be provided. Accordingly, the photosensitive conductor paste, other than the portion where a through-hole Tc is to be provided, is cured. Moreover, the remaining uncured paste is removed by a developer. As a result, an insulator layer 16g is formed. Thereafter, the steps of FIGS. 6 through 16 are repeated to form insulator layers 16b to 16f and coil conductor layers 18a to 18f, as shown in FIG. 17.

Next, a photosensitive insulator paste is applied by printing onto the insulator layer 16b and the coil conductor layer 18a, as shown in FIG. 18. Thereafter, the entire surface of the photosensitive insulator paste is exposed to light, as shown in FIG. 19. As a result, the photosensitive insulator paste is cured, so that an insulator layer 16a is formed. Further, an insulator paste is applied by printing onto the insulator layer 16a, thereby forming an insulator layer 25. Thus, a mother laminate made up of a plurality of laminates 12 is obtained.

Next, the mother laminate is cut into a plurality of unsintered laminates 12 by a dicing saw or suchlike. In addition, the laminates 12 are sintered under predetermined conditions.

Next, a conductive paste made of Ag is applied to opposite end surfaces of the laminate 12 by dipping, and the end surfaces are baked to form electrode bases. Lastly, the electrode bases are plated with Ni, Cu, Sn, or the like, thereby forming external electrodes 14a and 14b. By the foregoing process, the electronic component 10 is completed.

Effects

The electronic component 10 according to the present embodiment renders it possible to achieve a large inductance value. More specifically, the helical coil L has a high density of magnetic flux therein. Magnetic flux that does not flow

6

through the coil L passes through the surfaces of the coil conductor layers 18a to 18h. In this manner, when magnetic flux passes through the coil conductor layers 18a to 18h, eddy currents are set up, resulting in a reduced inductance value of the coil L.

Here, magnetic flux that does not flow through the coil L passes near the surfaces of the coil conductor layers 19a to 19d that are directed toward the inner circumference side of the coil L. Accordingly, eddy currents tend to be set up also near the surfaces of the coil conductor layers 19a to 19d that are directed toward the inner circumference side of the coil L. Therefore, in the electronic component 10, the surfaces of the coil conductor layers 19a to 19d that are directed toward the inner circumference side of the coil L have recesses Ga to Gd provided so as to be set back toward the outer circumference side of the coil L. As a result, the coil conductor layers 19a to 19d are thinner in the top-bottom direction near the surfaces directed toward the inner circumference side of the coil L. Accordingly, the distance that the magnetic flux passes through the coil conductor layers 19a to 19d becomes shorter. Thus, eddy currents which are set up in the coil conductor layers 19a to 19d are reduced, so that the inductance value of the coil L can be inhibited from being reduced. Note that the computer simulations to be described below demonstrate that the depth D1 of the recesses Ga to Gd is preferably 6 μm or more, which is 40% or less of the width W1 or W2 of the coil conductor layers 18a to 18h.

Computer Simulations

To confirm that the foregoing correctly describes the principle of increasing the inductance value of the coil L, the present inventors carried out computer simulations to be described below. The coil conductor layers 19a to 19d had respective recesses Ge to Gh provided in the surfaces directed toward the outer circumference side of the coil L, as shown in the enlarged view in FIG. 3. The depth of the recesses Ge to Gh is denoted by D2. The inventors calculated inductance values of the coil L with different values of the depths D1 and D2. The details of first through third models used in the computer simulations will be described below.

First Model:

Depth D1: 0 μm

Depth D2: 0 μm

Second Model:

Depth D1: 10 μm

Depth D2: 0 μm

Third Model:

Depth D1: 0 μm

Depth D2: 10 μm

For the first model, the inductance value was 2.276 nH. For the second model, the inductance value was 2.321 nH. That is, the inductance value for the second model was higher by 0.045 nH than that for the first model. On the other hand, for the third model, the inductance value was 2.282 nH. That is, the inductance value for the third model is higher only by 0.006 nH than that for the first model. In this manner, it can be appreciated that, in the case where the coil conductor layers 19a to 19d have the recesses Ga to Gd provided in the surfaces directed toward the inner circumference side of the coil L, the inductance value of the coil L is higher than in the case where the coil conductor layers 19a to 19d have the recesses Ga to Gd in the surfaces directed toward the outer circumference side of the coil L. Therefore, on the basis of the computer simulations, it is thought that by providing the recesses Ga to Gd, it is rendered possible to reduce eddy currents set up in the

coil conductor layers **19a** to **19d**, so that the inductance value of the coil L can be inhibited from being reduced.

Next, to find an optimal depth **D1** for the recesses **Ga** to **Gd**, fourth through seventh models as detailed below were created, and inductance values for the models were calculated.

Fourth Model:

Width (**W1** or **W2**) of the coil conductor layers **19a** to **19d**: 70 μm

Thickness of the coil conductor layers **19a** to **19d**: 12 μm

Fifth Model:

Width (**W1** or **W2**) of the coil conductor layers **19a** to **19d**: 60 μm

Thickness of the coil conductor layers **19a** to **19d**: 12 μm

Sixth Model:

Width (**W1** or **W2**) of the coil conductor layers **19a** to **19d**: 40 μm

Thickness of the coil conductor layers **19a** to **19d**: 12 μm

Seventh Model:

Width (**W1** or **W2**) of the coil conductor layers **19a** to **19d**: 40 μm

Thickness of the coil conductor layers **19a** to **19d**: 8 μm

For the fourth through seventh models, inductance values of the coil L were calculated with different values of the depth **D1** of the recesses **Ga** to **Gd**. FIG. 20 is a graph showing simulation results. The vertical axis represents the percentage change of the inductance value, and the horizontal axis represents the depth **D1** of the recesses **Ga** to **Gd**. The percentage change of the inductance value refers to a percentage change relative to the inductance value where the depth **D1** is 0 μm .

It can be appreciated from FIG. 20 that for all of the fourth through seventh models, the inductance value increased with the depth **D1**. In addition, for all of the fourth through seventh models, the inductance value barely increased where the depth **D1** was 6 μm or more. Therefore, it can be appreciated that the depth **D1** is preferably 6 μm or more. Note that the inventors calculated inductance values with the depth **D1** at 10 μm . Thus, the depth **D1** is preferably 10 μm or less.

Furthermore, for the fourth model, it was found that the inductance value barely changed where the depth **D1** was up to 30 μm . For the fourth model, the width **W1** was 70 μm . Accordingly, for the fourth model, the inductance value barely changed where the depth **D1** was 42.8% or less of the width **W1**. Similarly, for the fifth model, it was found that the inductance value barely changed where the depth **D1** was up to 25 μm . For the fifth model, the width **W1** was 60 μm . Accordingly, for the fifth model, the inductance value barely changed where the depth **D1** was 42.5% or less of the width **W1**. For the sixth model, it was found that the inductance value barely changed where the depth **D1** was up to 16 μm . For the sixth model, the width **W1** was 40 μm . Accordingly, for the sixth model, the inductance value barely changed where the depth **D1** was 40.0% or less of the width **W1**. For the seventh model, it was known that the inductance value barely changed where the depth **D1** was up to 16 μm . For the seventh model, the width **W1** was 40 μm . Accordingly, for the seventh model, the inductance value barely changed where the depth **D1** was 40.0% or less of the width **W1**. Thus, the depth **D1** of the recesses **Ga** to **Gd** is preferably 40% or less of the width **W1** or **W2** of the coil conductor layers **18a** to **18h**.

Other dimensions of the coil conductor layers **19a** to **19d** will also be described. It is preferable that the portions of the coil conductor layers **18a**, **18c**, **18e**, and **18g** that are positioned on the insulator layers **16b**, **16d**, **16f**, and **16h**, respectively, as shown in FIG. 3, have a thickness **H1** of from 8 μm to 12 μm . Moreover, it is preferable that the portions of the coil conductor layers **18a**, **18c**, **18e**, and **18g** that are positioned in the openings **Op1** to **Op4**, respectively, have a thick-

ness **H3** of 7 μm . In addition, the coil conductor layers **18b**, **18d**, **18f**, and **18h** preferably have a thickness **H2** of from 8 μm to 12 μm .

Method for Measuring Recess Depth

The method for measuring the depth **D1** of the recesses **Ga** to **Gd** will be described below with reference to the drawings.

Initially, curable resin is applied to the electronic component **10** and hardened. The electronic component **10** with the hardened resin is ground to expose a cross section of the coil conductor layer **19a**. Further, the exposed cross section of the coil conductor layer **19a** is buffed to eliminate grounding flaws therefrom. Thereafter, an image of the cross section of the coil conductor layer **19a** is taken by a laser microscope (VK-8700 from Keyence Corp.). FIG. 21 is a photograph showing the cross-sectional structure of the coil conductor layer **19a**.

In actuality, the cross-sectional shape of the coil conductor layer **19a** is significantly different from the shape of an H, as shown in FIG. 21. Therefore, in the case where the depth **D1** of any of the recesses **Ga** to **Gd** is measured, the bottom of that recess is determined first. For example, in the case of the recess **Ga**, its bottom, which is denoted by **P1** in FIG. 21, is the closest portion to the outer circumference side of the coil L. Next, the entrance of the recesses **Ga** to **Gd** is determined. For example, in the case of the recess **Ga**, its entrance, which is denoted by **P2**, corresponds to the closest portion of the coil conductor layer **19a** to the inner circumference side of the coil L, as shown in FIG. 21. Thereafter, the distance between the portions **P1** and **P2** in the right-left direction is measured and set as a depth **D1**. By the above process, the depth **D1** can be measured.

Modification

Hereinafter, an electronic component **10a** according to a modification will be described with reference to the drawings. FIG. 22 is a cross-sectional structure view of the coil conductor layer **19a**. For the external oblique view and the exploded oblique view of the electronic component **10a**, FIGS. 1 and 2 will be referenced.

The electronic component **10a** differs from the electronic component **10** in terms of the cross-sectional shape of the coil conductor layers **19a** to **19d**. In the following, the cross-sectional shape of the coil conductor layers **19a** to **19d** will be described, but any descriptions of other features will be omitted.

The surface of the coil conductor layer **18c** that is opposite to the coil conductor layer **18b** with the insulator layer **16c** positioned therebetween, i.e., the upper surface of the coil conductor layer **18c**, is concave. Accordingly, the distance between the coil conductor layers **18b** and **18c** is increased. As a result, an increase in insertion loss in the electronic component **10a** due to proximity effect is inhibited. While the foregoing has been given by taking as an example the relationship between the coil conductor layers **18b** and **18c**, the same can be said of the relationship between the coil conductor layers **18d** and **18e** and also of the relationship between the coil conductor layers **18f** and **18g**.

To clearly demonstrate that the insertion loss in the electronic component **10a** is suppressed, the inventors carried out computer simulations to be described below. Specifically, the inventors created eighth through tenth models as will be detailed below, and studied the relationship of the frequency of a high-frequency signal with a quality factor.

The specifications common among the eighth through tenth models are as follows:

Width (W1 or W2) of each coil conductor layer: 65 μm

Number of coil conductor layers: 5

Number of winds of the coil L: 4.5

Distance from the coil L to the end surface of the laminate: 23 μm

The distance L1 between the coil conductor layers 18b and 18c is shown below for each model:

Eighth model: 5 μm

Ninth model: 10 μm

Tenth model: 15 μm

FIG. 23 is a graph showing simulation results. The vertical axis represents the quality factor, and the horizontal axis represents the frequency. It can be appreciated from FIG. 23 that the quality factor peaks at a higher level as the distance L1 increases. Specifically, it can be appreciated that an increase in the distance L1 between the coil conductor layers 18b and 18c due to the upper surface of the coil conductor layer 18c being concave results in an increase in the quality factor in the electronic component 10a. Thus, it can be appreciated that the insertion loss in the electronic component 10a can be suppressed by increasing the distance L1.

Furthermore, it can be appreciated from FIG. 23 that the peak quality factor was significantly improved when the distance L1 was 10 μm or more. Thus, the distance L1 is preferably 10 μm or more.

Other Embodiments

The present disclosure is not limited to the electronic components 10 and 10a, and variations can be made within the spirit and scope of the disclosure.

Note that the electronic components 10 and 10a are provided with the recesses Ge to Gh, but the recesses Ge to Gh are not indispensable.

Furthermore, in the case of the electronic components 10 and 10a, the coils L are helical coils, but they may be any coils that are in the form of, for example, spirals when viewed in a top view. Moreover, the coils L may be helical coils formed by connecting a plurality of spiral coil conductor layers.

Although the present disclosure has been described in connection with the preferred embodiment above, it is to be noted that various changes and modifications are possible to those who are skilled in the art. Such changes and modifications are to be understood as being within the scope of the disclosure.

What is claimed is:

1. An electronic component comprising:

a laminate formed by laminating a plurality of insulator layers;

a coil including linear coil conductor layers laminated along with the insulator layers, the coil having a spiral form; and

via-hole conductors extending through the insulator layers and connecting the coil conductor layers, wherein,

in a cross section perpendicular to a direction in which the coil conductor layers extend, the coil conductor layers have recesses provided in surfaces directed toward an inner circumference side of the coil, the recesses being set back toward an outer circumference side of the coil, the recesses are positioned in portions of the coil conductor layers a spaced distance from the via-hole conductors along the direction in which the coil conductor layers extend, and

the recesses have a depth of greater than or equal to 6 μm and less than 20 μm .

2. The electronic component according to claim 1, wherein a depth of the recesses is 40% or less of the width of a coil conductor layers.

3. The electronic component according to claim 1, wherein,

the insulator layers include first insulator layers and second insulator layers laminated thereon,

the coil conductor layers include first and second coil conductor layers,

the first coil conductor layers are provided on the first insulator layers,

the second insulator layers have linear openings narrower than the first and second coil conductor layers, the openings overlapping with the first coil conductor layers when viewed in a plan view in a direction of lamination, and

the second coil conductor layers are provided on the second insulator layers so as to be partially positioned in the openings.

4. The electronic component according to claim 1, wherein the recesses have a depth of greater than or equal to 6 μm and less than or equal to 16 μm .

5. An electronic component comprising:

a laminate formed by laminating a plurality of insulator layers;

a coil including linear coil conductor layers laminated along with the insulator layers, the coil having a helical form which windingly extends in a direction of lamination; and

via-hole conductors extending through the insulator layers and connecting the coil conductor layers, wherein,

in a cross section perpendicular to a direction in which the coil conductor layers extend, the coil conductor layers have recesses provided in surfaces directed toward an inner circumference side of the coil, the recesses being set back toward an outer circumference side of the coil,

the recesses are positioned in portions of the coil conductor layers a spaced distance from the via-hole conductors along the direction in which the coil conductor layers extend, and

the recesses have a depth of greater than or equal to 6 μm and less than 20 μm .

6. The electronic component according to claim 5, wherein a depth of the recesses is 40% or less of the width of the coil conductor layers.

7. The electronic component according to claim 5, wherein,

the insulator layers include first insulator layers and second insulator layers laminated thereon,

the coil conductor layers include first and second coil conductor layers,

the first coil conductor layers are provided on the first insulator layers,

the second insulator layers have linear openings narrower than the first and second coil conductor layers, the openings overlapping with the first coil conductor layers when viewed in a plan view in a direction of lamination, and

the second coil conductor layers are provided on the second insulator layers so as to be partially positioned in the openings.

8. The electronic component according to claim 7,
wherein,
the first insulator layers and the second insulator layers are
laminated so as to alternate with each other,
the coil is a helical coil formed by connecting the coil 5
conductor layers each including the first and second coil
conductor layers, and
the second coil conductor layers have concave surfaces
each being opposite to the first coil conductor layer with
the first insulator layer positioned therebetween. 10

9. The electronic component according to claim 5, wherein
the recesses have a depth of greater than or equal to 6 μm and
less than or equal to 16 μm .

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 9,362,042 B2
APPLICATION NO. : 14/203497
DATED : June 7, 2016
INVENTOR(S) : Masayuki Yoneda et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Specification

In column 6, line 50, replace “Depth D1: 0 oom” with “Depth D1: 0 μm ”;

In column 7, line 17, replace “Thickness of the coil conductor layers 19a to 19d: 12” with “Thickness of the coil conductor layers 19a to 19d: 12 μm ”.

Signed and Sealed this
Sixth Day of September, 2016



Michelle K. Lee
Director of the United States Patent and Trademark Office